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Shock Mitigation Analysis Using Recycled Composites for Application to Guided Projectiles

by Zachary Geesey, Barry Kline, and Bryant Nelson

ARL-CR-721   **September 2013**

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REPORT DOCUMENTATION PAGE

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
September 2013	Final	March 2012–September 2012

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Shock Mitigation Analysis Using Recycled Composites for Application to Guided Projectiles	1120-1120-99
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
Zachary Geesey,[*] Barry Kline,[†] and Bryant Nelson[†]	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
U.S. Army Research Laboratory ATTN: RDRL-WML-F Aberdeen Proving Ground, MD 21005-5066	ARL-CR-721

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

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14. ABSTRACT

Accurately, quickly, and cheaply simulating a gun launch to detect mechanical faults in projectiles is a challenge in the Weapons and Materials Research Directorate's Lethality Division. Currently, the most accurate method is to machine the rounds, fire them, and record the structural failures of the round. A cheaper but less accurate method is to put rounds or parts in an air gun and fire it to record the same properties. However, despite the advantages of the air gun, both methods are expensive and time consuming. The cheapest and quickest technique of testing parts is to put them in a high-acceleration impact table. This machine induces a peak acceleration similar to that which is encountered in a gun launch, but the overall event is shorter. The acceleration and duration can be changed by using different amounts and types of padding on the shock table. There are many different types of materials with properties that could offer a solution to finding a more accurate acceleration profile. The goal of the experiments detailed in this report was to determine if recycled cardboard could produce a more realistic shock simulation than the felt material currently used. Creating a more accurate simulation will contribute to the overall goal of finding structural design faults in guided projectile components.

15. SUBJECT TERMS

shock, mitigation, recycled, composites, projectile, structure, analysis

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Zachary Geesey
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UU	30	**19b. TELEPHONE NUMBER** (Include area code)
Unclassified	Unclassified	Unclassified			410-306-0771

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Acknowledgments

The author of this report, Zachary Geesey, is currently a sophomore at Drexel University and is studying in a dual-degree program to obtain Bachelor's and Master's degrees of science in electrical engineering. Some of Zach's prior experience in research comes from his freshmen design project where he designed and constructed the circuitry for an underwater submersible with 3 degrees of freedom. Zach is currently contracted in the U.S. Army Reserved Officers' Training Corps; after graduation, he will be commissioned as an officer in the U.S. Army. Following graduation, he plans to continue conducting high-level research in power and other types of electrical engineering.

1. Introduction/Background

This experiment was set up using the IMPAC 66 HVA shock-testing machine, which uses a 33-lb anvil and a bungee cord to induce a very sudden change in momentum. As seen in figures 1 and 2, the bungee cord is fastened to the anvil and then raised above the ground by a control mechanism that moves the drop table. After the table and anvil reach their specified height, the brakes on the anvil engage to hold it in place while the table is lowered. The brakes are then released, and the anvil thrusts downward toward the drop table, which is on top of a reaction mass supported by a hydro-pneumatic suspension system. The table, reaction mass, and hydro-pneumatic system react in a way so no equipment is damaged. The maximum height the anvil can be raised is 80 in above the drop table when the table is on the ground. The impact causes a large change in momentum, which can be dampened by placing more padding on the drop table. When the anvil hits the table, the change in acceleration is picked up by an accelerometer and displayed in an oscilloscope.[*] The procedure for using the IMPAC 66 HVA shock table can be seen in table 1.

The purpose of this experiment is to create an acceleration pattern that will be very similar to an air gun launch. Three theoretical models of the acceleration pattern created in an air gun can be seen in figure 3. The notable aspects of this graph are the peak acceleration near 9000 g's and the duration of the shock, which is approximately 4–6 ms.

Prior to this experiment, a thick felt was used as padding for the anvil. This was a very durable material, which was used to produce the maximum acceleration that would be encountered in a gun launch. However, the material needed to be shocked two or three times to produce consistent results.[†] This is because when the felt is new, it has no permanent deformations or markings that will occur after a few shock tests. While the felt was good for producing a high maximum acceleration, its shock duration was only a few hundred microseconds. This occurs because after conditioning, the felt has very little room to compress. If the material has less room for compression, a higher acceleration occurs in a shorter period of time to bring the anvil to a stop. The cardboard was chosen because it is a cheap and easily available material that has more space to compress than the felt. The empty space means that it would be necessary to use more cardboard than felt to stop the motion of the anvil. The relative thicknesses of the cardboard with respect to the anvil can be seen in figures 4 and 5. Because of the increase of overall thickness and empty space in the material, it was hypothesized that if the anvil was raised

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[*]Peregino, P. J., II; Bukowski, E. *Development and Evaluation of a Surface-Mount, High-G Accelerometer*; ARL-TR-3331; U.S. Army Research Laboratory: Aberdeen, MD, September 2004.

[†]Childers, M. A. *Evaluation of the IMPAC66 Shock Test Machine, Serial No. 118, ARL-TR-2840*; U.S. Army Research Laboratory: Aberdeen, MD, October 2002.

to the same height as with the felt padding, it would allow longer shock duration with a lower peak.
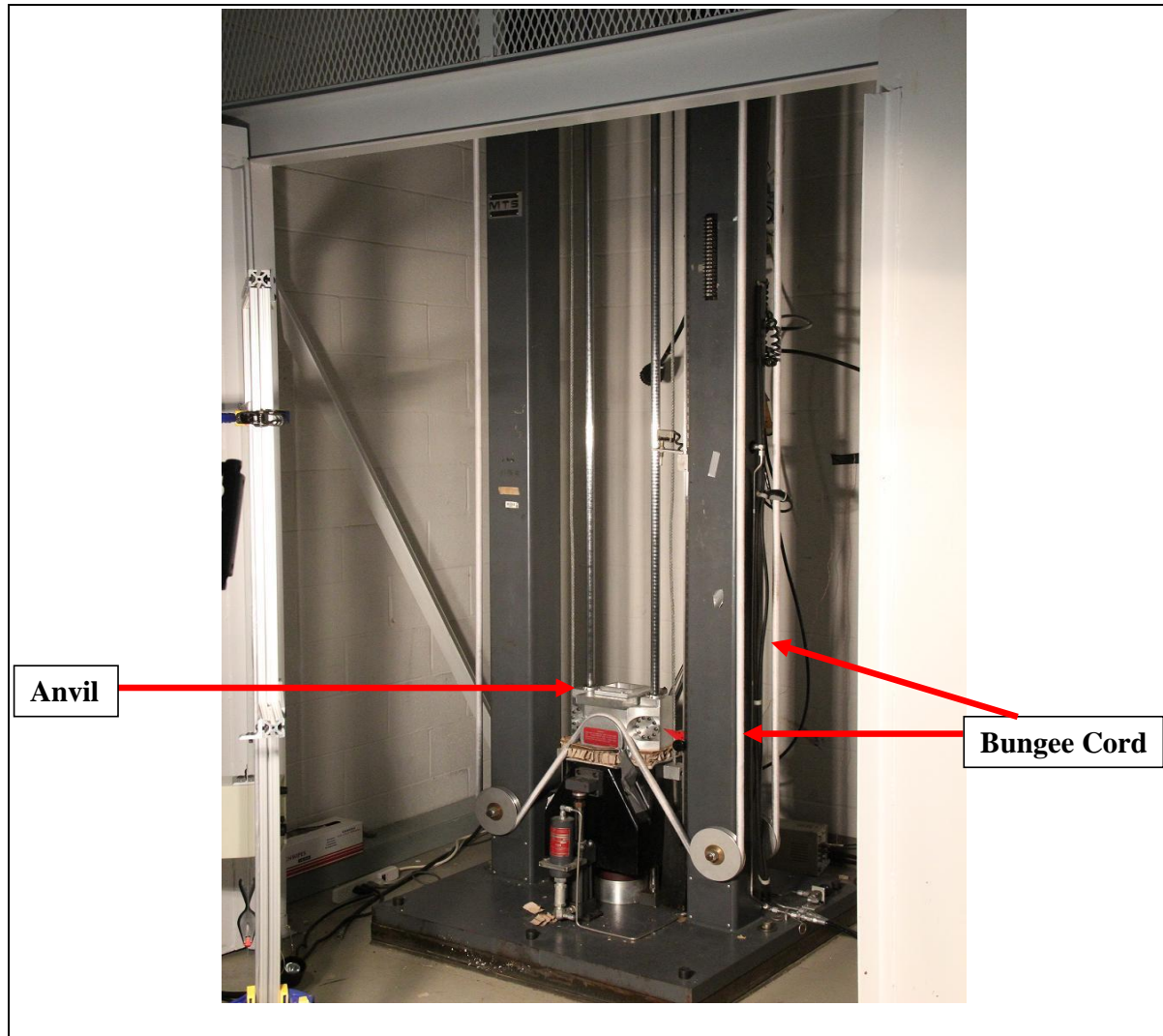

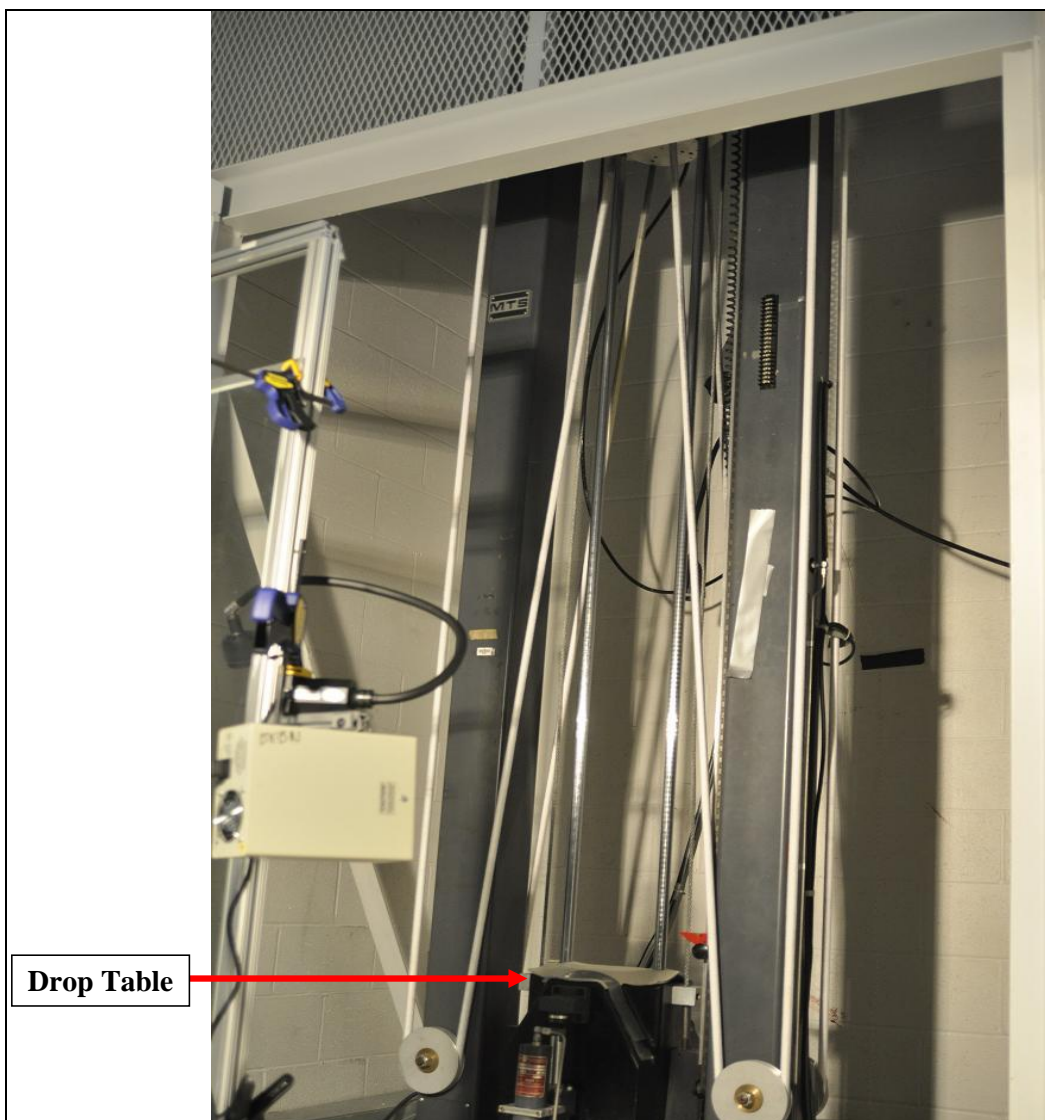Figure 1. IMPAC 66 HVA shock table.

Figure 2. Anvil in raised position for experimental setup used in run 1, baseline padding.
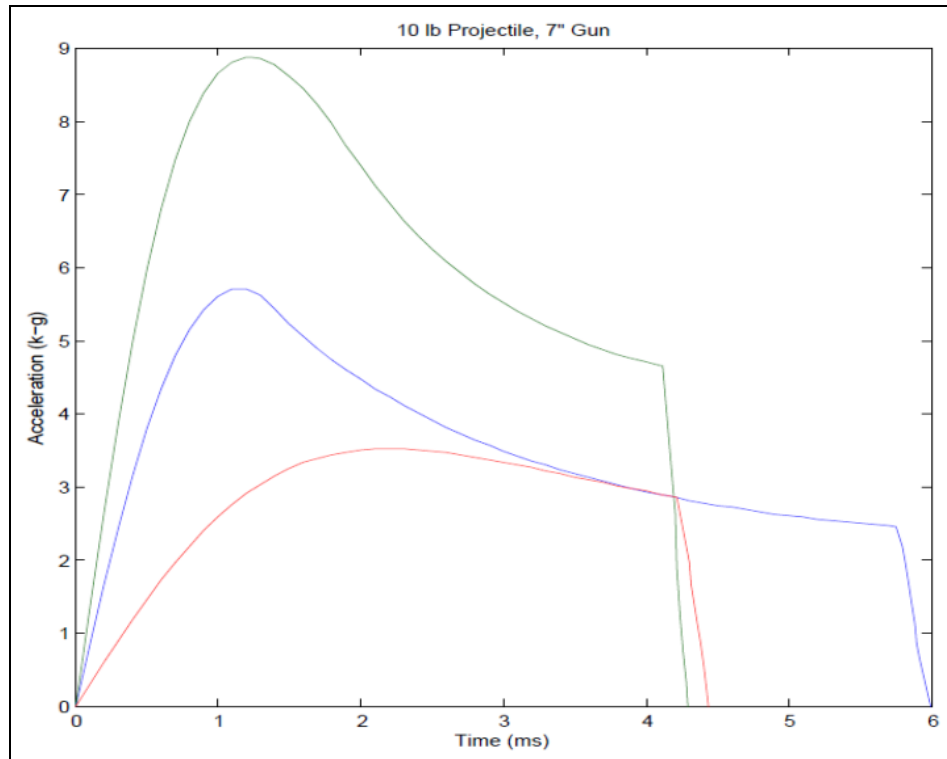
Figure 3. Theoretical acceleration graph from air gun launch.
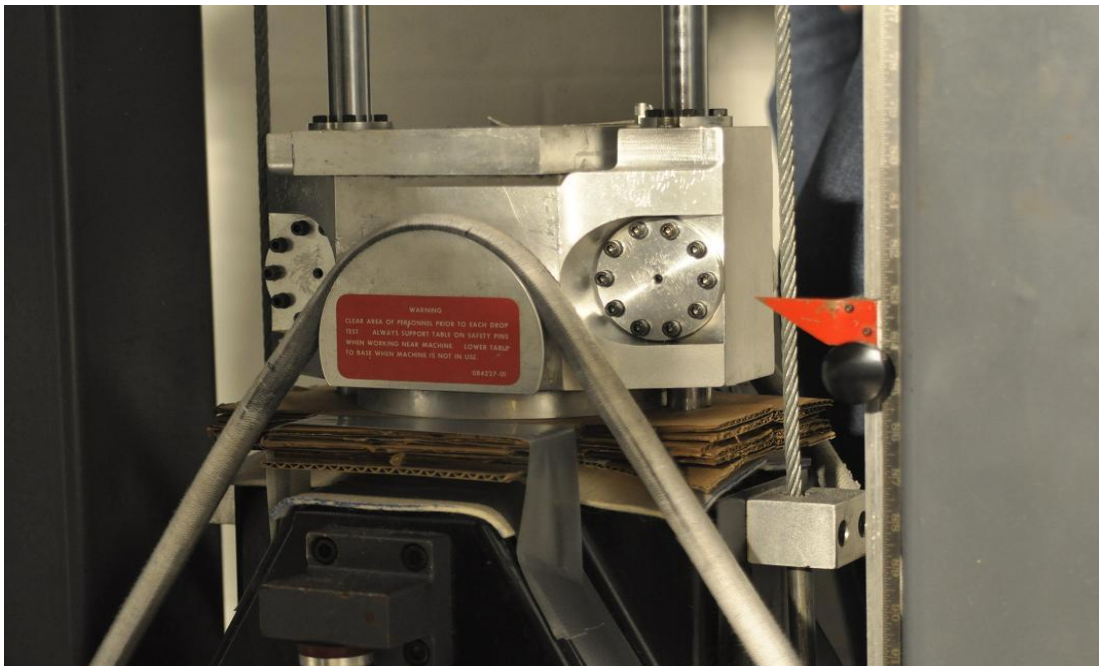
Figure 4. Setup for run 2, six thin pieces of cardboard.
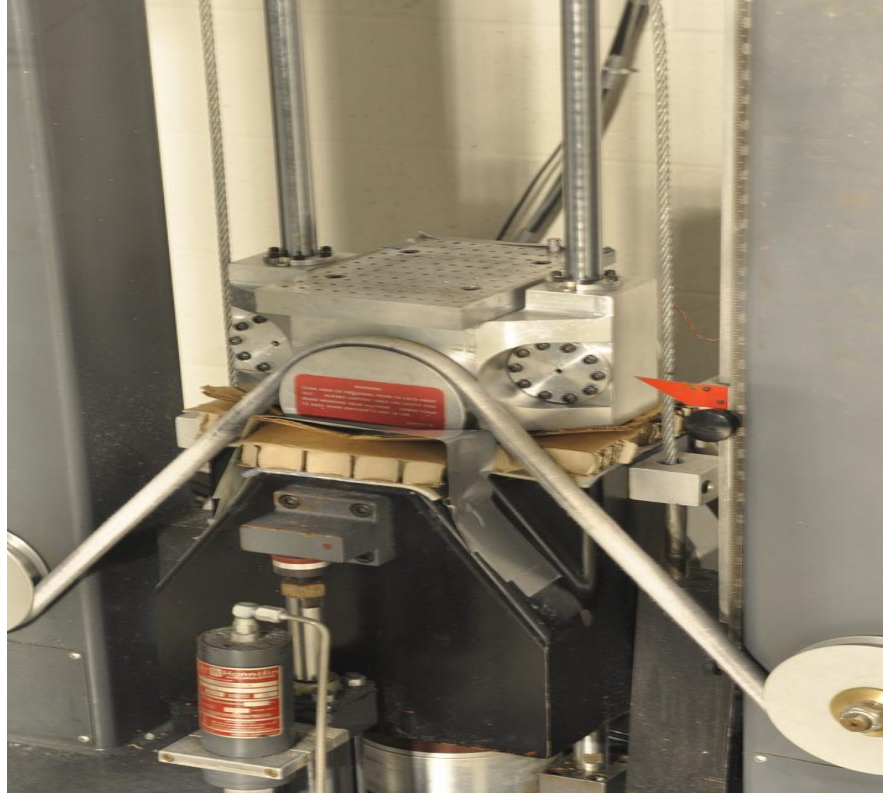
Figure 5. Setup for run 4, one thick piece and one thin piece of cardboard.

2. Experimental Setup

To perform the shock tests a variety of equipment was used, as follows:

- Infiniium oscilloscope (model 54825A)

- IMPAC 66 HVA shock testing machine

- PCB Piezotronics accelerometer (model 350B23)

- 20 thick pieces of cardboard (≈1.17-in-thick for each piece)

- Three 1/8-in pieces of felt

- One 1/4-in piece of felt

- 35 thin pieces of cardboard (≈0.155-in-thick for each piece)

- Duct tape

Table 1. Procedure for IMPAC HVA 66 shock table use.

Step No.	Action Taken	Comments
1	Remove the bungee cord from guides on the anvil.	Ear and eye protection should be worn at all times.
2	Lift the anvil by hand, place the padding on the drop table, and tape down the padding.	One person held the anvil while another person put the padding down.
3	Place the anvil on top of the padding, and put the bungee cord back on the guides of the anvil.	—
4	Raise the table and anvil to desired height.	This experiment set the maximum height at 80 in.
5	Apply brakes to hold the anvil in place.	—
6	Lower the drop table.	—
7	Set oscilloscope to record a single sweep.	The oscilloscope was set to have 500 µs per division and 2 V per division.
8	Release brakes, dropping the anvil.	—
9	Record the data on the oscilloscope using photographs and floppy disk.	The data were taken from the oscilloscope and put into MATLAB for analysis.

3. Experiment/Calculations

Conservation of energy is the foundation upon which this experiment is made. Energy is conserved during the experiment so that the work used to raise the anvil above the table is the maximum energy that the system can have. When the anvil is raised above the table, it has two types of potential energy—gravitational energy from raising the anvil (PE_{g1}) and elastic energy from the bungee cord (PE_{e1}). When the anvil is released and just about to hit the table, it has kinetic energy (KE_2) and some elastic potential energy (PE_{e2}). Therefore, the value of the total elastic potential energy depends upon the difference between the starting (x_1) and ending (x_2) elongation of the bungee cord.

$$PE_{g1} + PE_{e1} = Total\ E. \tag{1}$$

$$PE_{g1} + PE_{e1} = PE_{e2} + KE_2. \tag{2}$$

$$mgh + \frac{1}{2}k(x_1 - x_2) = \frac{1}{2}m(v_f)^2. Acceleration = \frac{Voltage}{0.000444^V/_g} . \tag{3}$$

If it is assumed that all potential energy is converted to kinetic energy and neglecting loss due to friction, the more potential energy that is put into the system, the faster the anvil will be moving right before impact. If the anvil is moving faster, it will have a much higher level of acceleration before coming to rest, depending upon the type of padding on the table surface.

Fifteen different shock tests were performed, each having a different amount and type of padding. However, there was always a 1/8-in piece of felt used for padding so that there was a baseline for the experimental data. The different configurations led to different amounts of acceleration recorded on the anvil. The changes in acceleration were picked up by an accelerometer on the shock table. The scale factor of the particular accelerometer used was 0.444 mV/g. To make the change from voltage to acceleration, the following equation is used:

$$Acceleration = \frac{Voltage}{0.000444\ ^V/_g}. \tag{4}$$

4. Results and Discussion

4.1 Results

The individual configurations for padding and the maximum acceleration obtained from each trial can be found in table 2. The acceleration versus time graphs can also be found in the table.

The maximum peak duration in table 2 was obtained by using a MATLAB program to extract the duration of time that the highest peak was above 1000 g's. This was used for all trials except for no. 15 because the maximum acceleration for trial 15 was much smaller than the other trials and would only account for approximately two-thirds of the peak. Since the minimum trigger acceleration was never more than one-sixth of the maximum acceleration for trials 1–14, the minimum acceleration for trial 15 was lowered to 500 g's.

After these data were collected, a dual-axis scatter plot was made to compare the maximum acceleration and maximum peak duration versus the total thickness of padding used on the table. The graph in figure 6 shows that less padding will lead to a larger max acceleration and smaller peak duration, and more padding will lead to a smaller maximum acceleration and larger peak duration. This trend does have some variation based on the type of padding used and the orientation of the padding; but overall, the pattern holds true.

Table 2. Maximum accelerations achieved.

Trial No.	Padding	Total Thickness of Padding (in)	Max Voltage (V)	Equivalent Maximum Acceleration (g's)	Maximum Peak Duration (μs)
1	1/8-in felt fabric	0.125	12.1	[a]27,300	180
2	1/8-in felt fabric 6 thin cardboard	1.055	5.41	12,200	330
3	1/8-in felt fabric 1 thick cardboard	1.295	7.27	16,400	270
4	1/8-in felt fabric 1 thin cardboard 1 thick cardboard	1.45	6.55	14,800	295
5	1/8-in felt fabric 12 thin cardboard	1.985	2.54	5,700	485
6	1/8-in felt fabric 3 thick cardboard	3.635	2.09	4,700	520
7	1/8-in felt fabric 2 thin cardboard 1 1/4-in felt fabric 2 thin cardboard	0.995	4.16	9,400	395
8	1/8-in felt fabric 1 thick cardboard 1 1/4-in felt fabric 1 thick cardboard	2.715	2.46	5,500	615
9	1/8-in felt fabric 1 1/8-in felt fabric 4 thin cardboard 1 1/8-in felt fabric	0.995	4.28	9,600	390
10	1/8-in felt fabric 1 1/8-in felt fabric 1 thick cardboard 1 1/8-in felt fabric	1.545	3.99	9,000	365
11	1/8-in felt fabric 1 1/4-in felt fabric 4 thin cardboard	0.995	4.47	10,000	385
12	1/8-in felt fabric 1 1/4-in felt fabric 1 thick cardboard	1.545	3.81	8,600	390
13	1/8-in felt fabric 4 thin cardboard 1 1/4-in felt fabric	0.995	4.64	10,400	355
14	1/8-in felt fabric 1 thick cardboard 1 1/4-in felt fabric	1.545	3.88	8,700	385
15	1/8-in felt fabric 4 thick cardboard	4.805	1.28	2,900	820

[a]The oscilloscope was unable to capture the true value of the maximum acceleration because the range was not large enough.
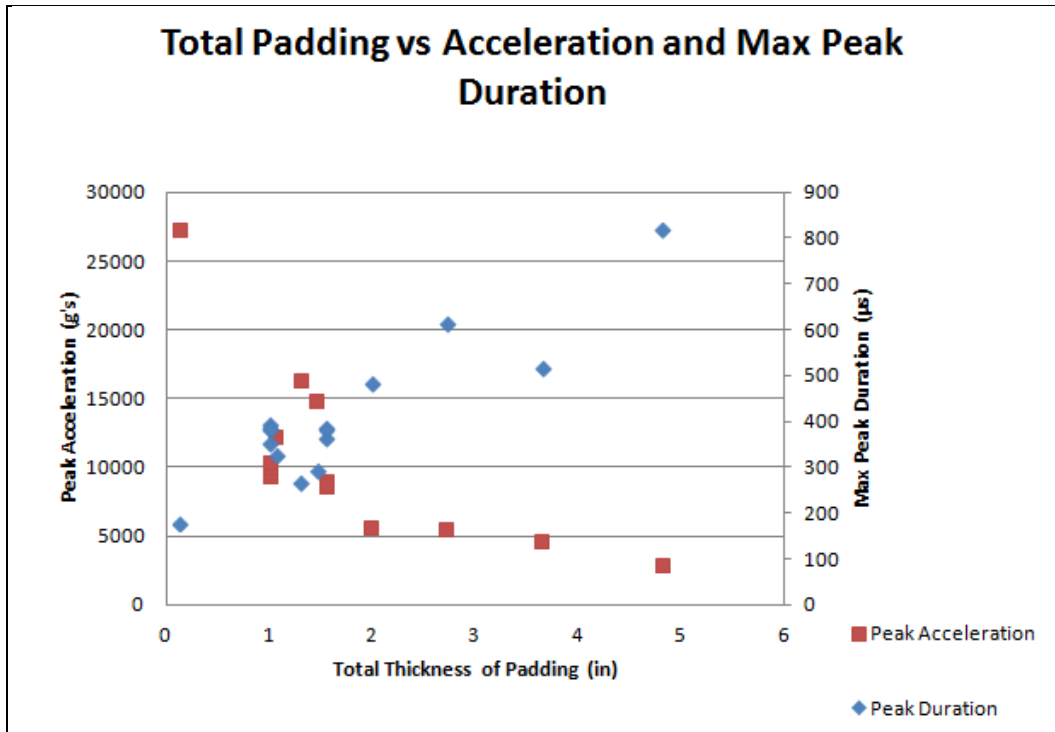
Figure 6. Total thickness of padding vs. maximum peak acceleration and maximum peak duration.

4.2   Graphs

Figures 7–23 are graphs created from the output voltage of the accelerometer on the anvil versus time. All configurations for padding are labeled from bottom to top. The first piece of padding in the comment is closest to the base of the platform, and the last piece of padding is on the top of the stack. We were not able to collect an accurate representation of data from the baseline trial because the oscilloscope range was not large enough to capture the maximum acceleration of the trial.
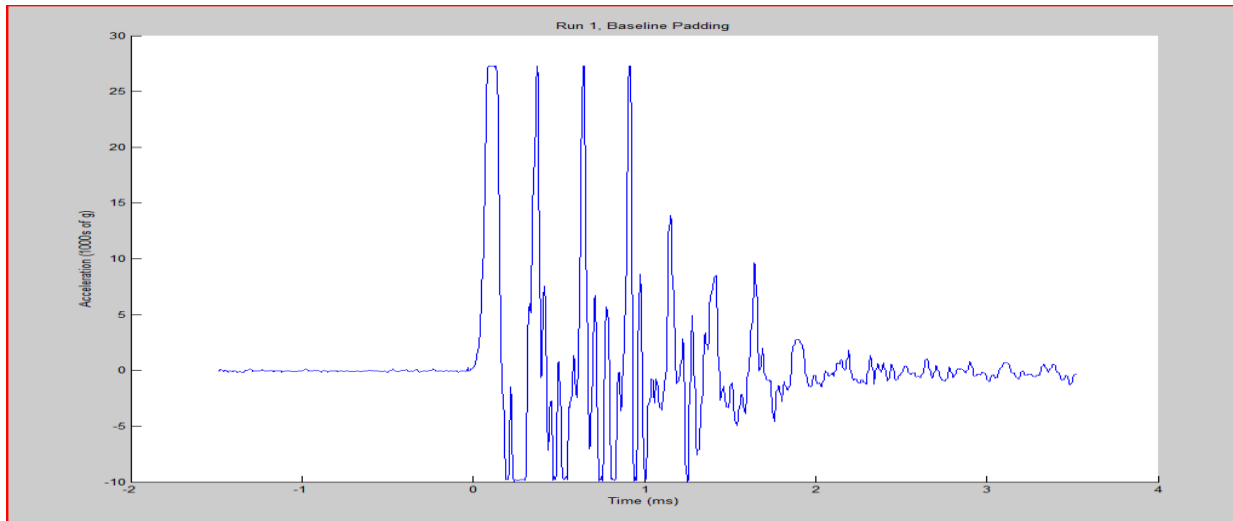
Figure 7. Trial 1: Baseline of 1/8-in fabric.
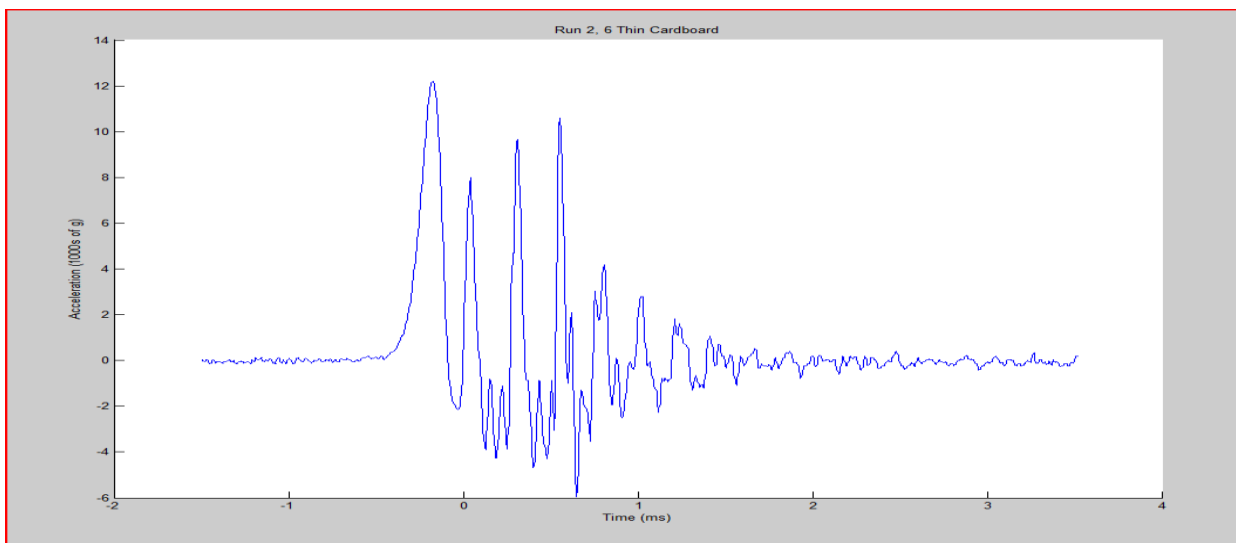
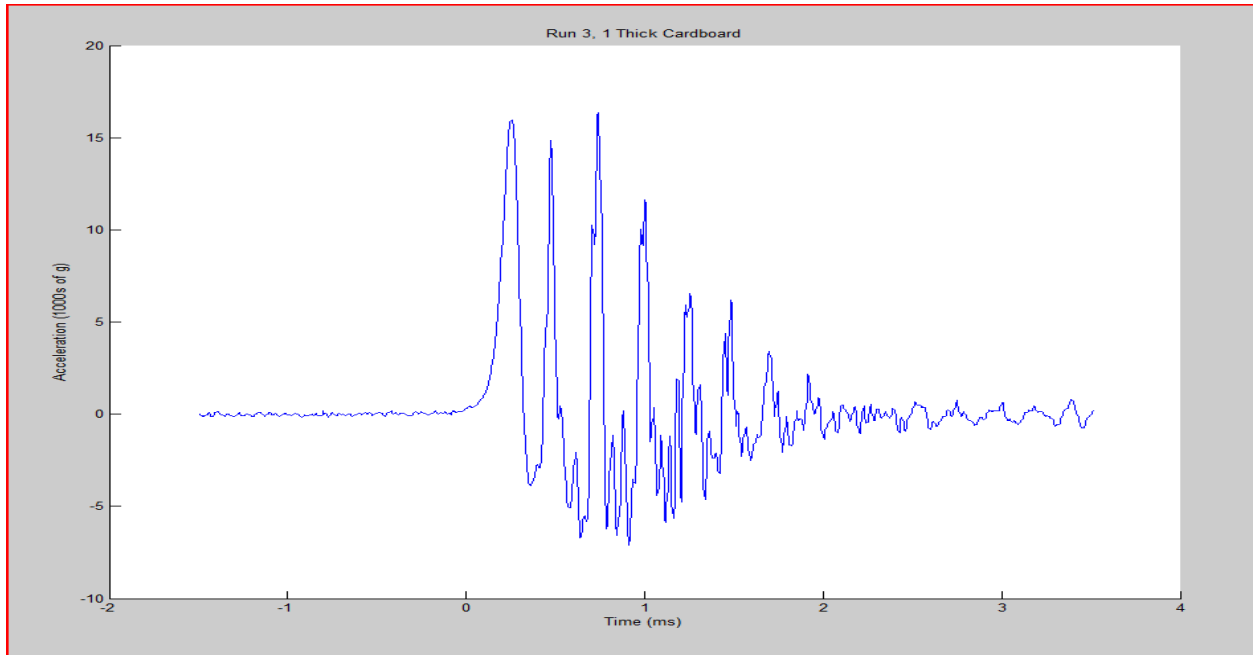Figure 8. Trial 2: Six thin pieces of cardboard.

Figure 9. Trial 3: One thick piece of cardboard.
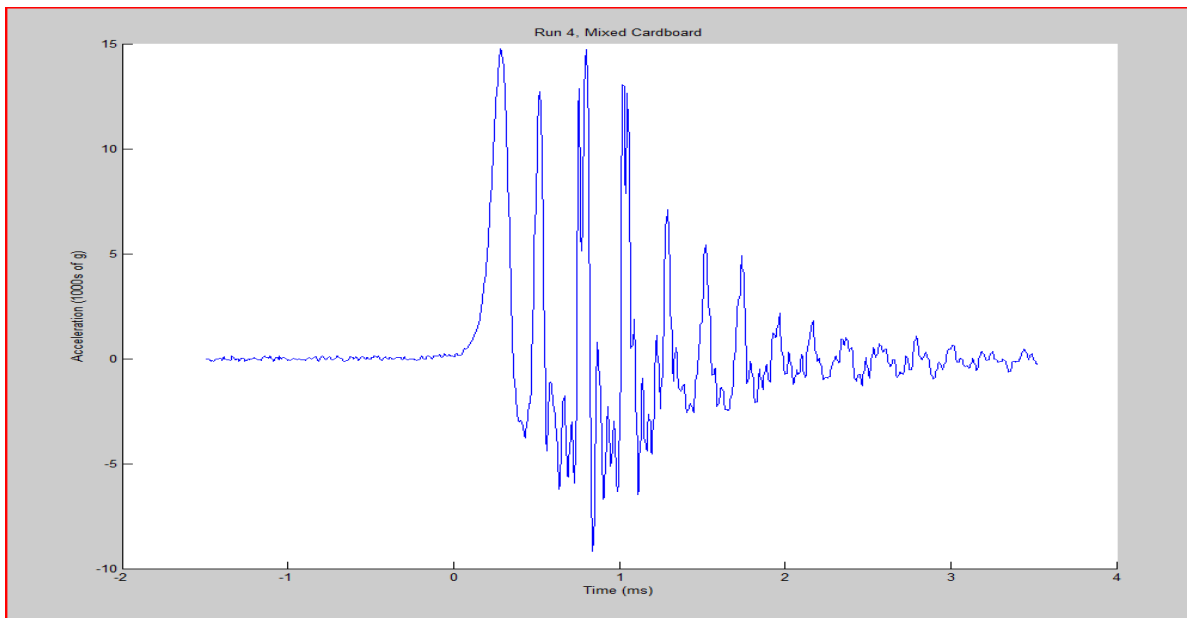

Figure 10. Trial 4: One thick and one thin piece of cardboard.
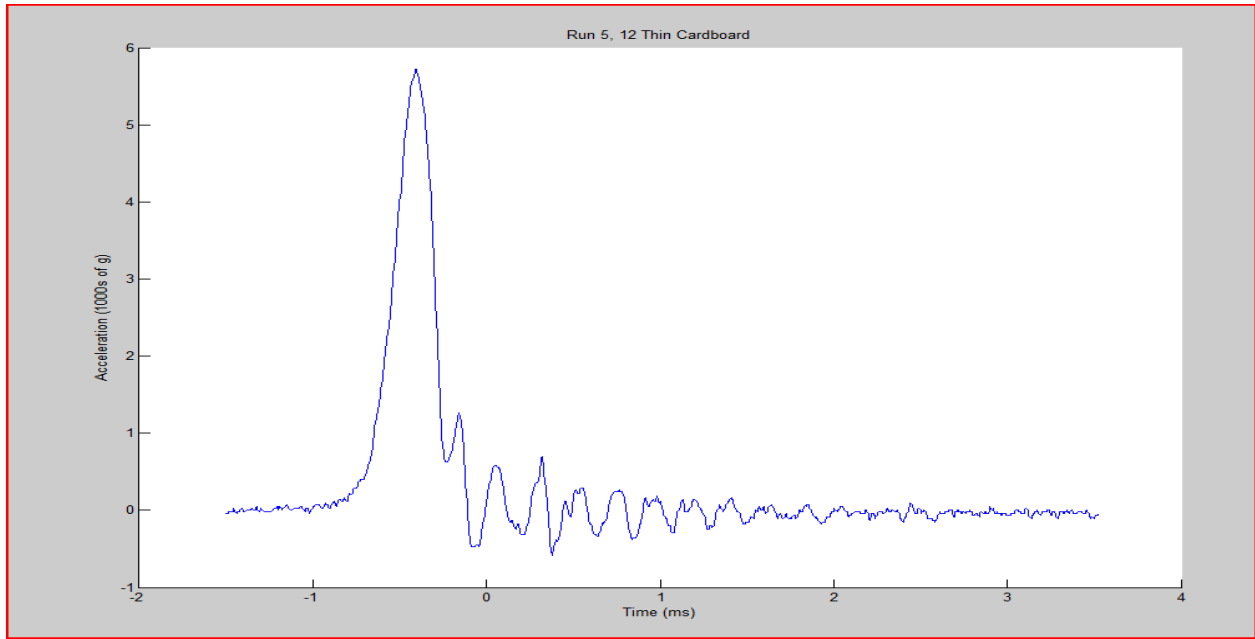
Figure 11. Trial 5: Sample of 12 thin pieces of cardboard.
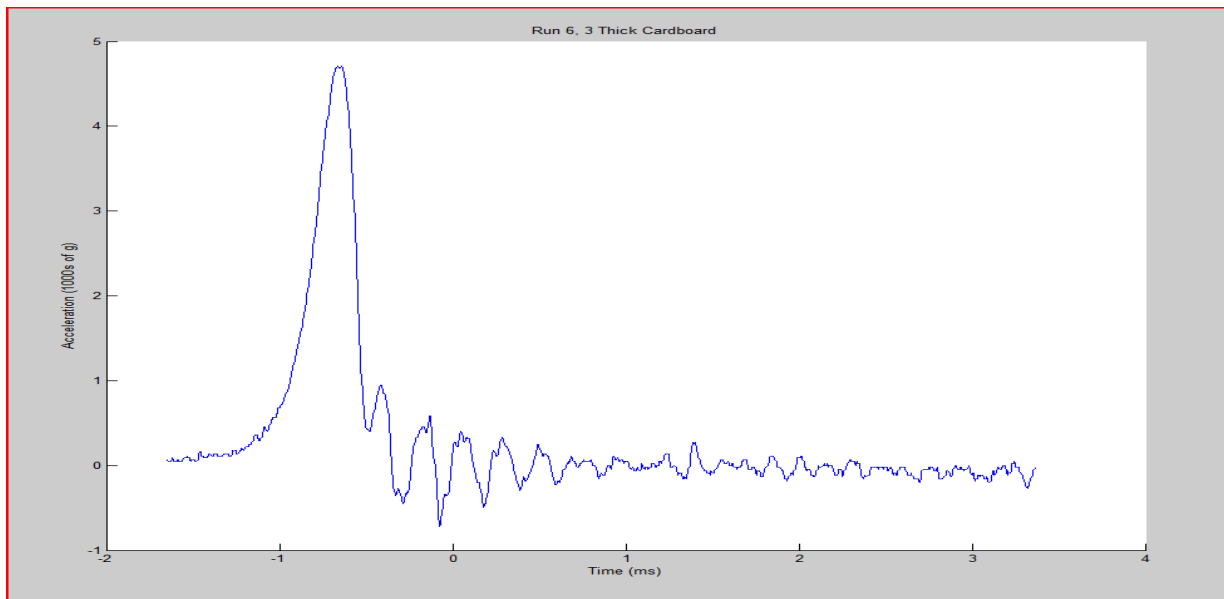

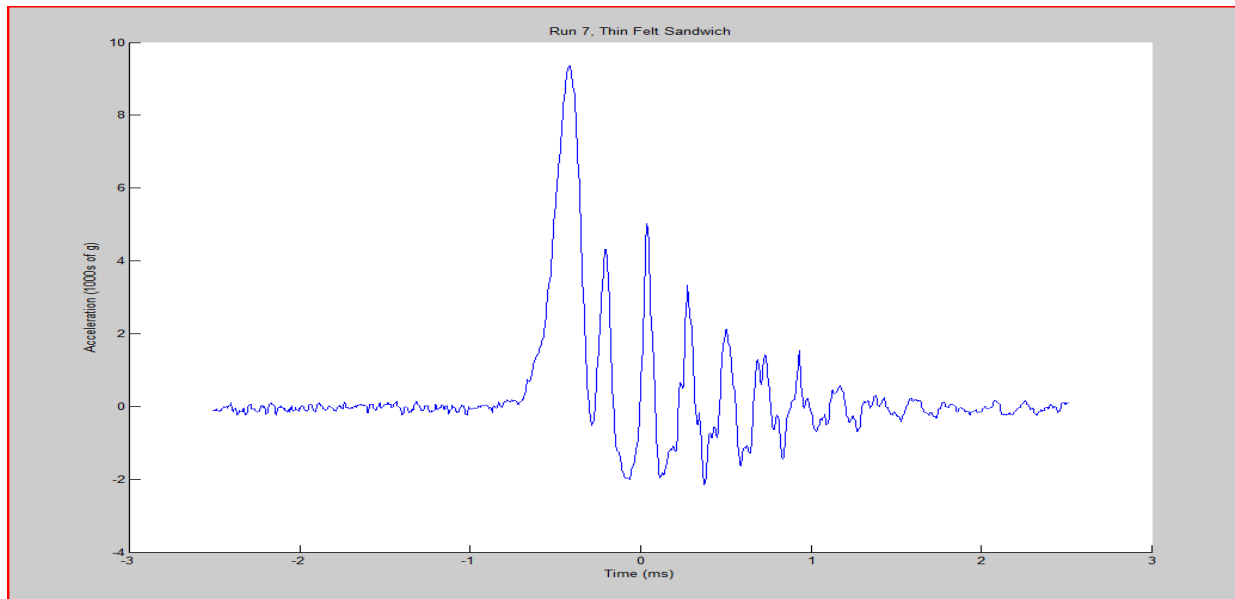Figure 12. Trial 6: Three thick pieces of cardboard.

Figure 13. Trial 7: Two thin pieces of cardboard, 1 1/4-in fabric, and two thin pieces of cardboard.
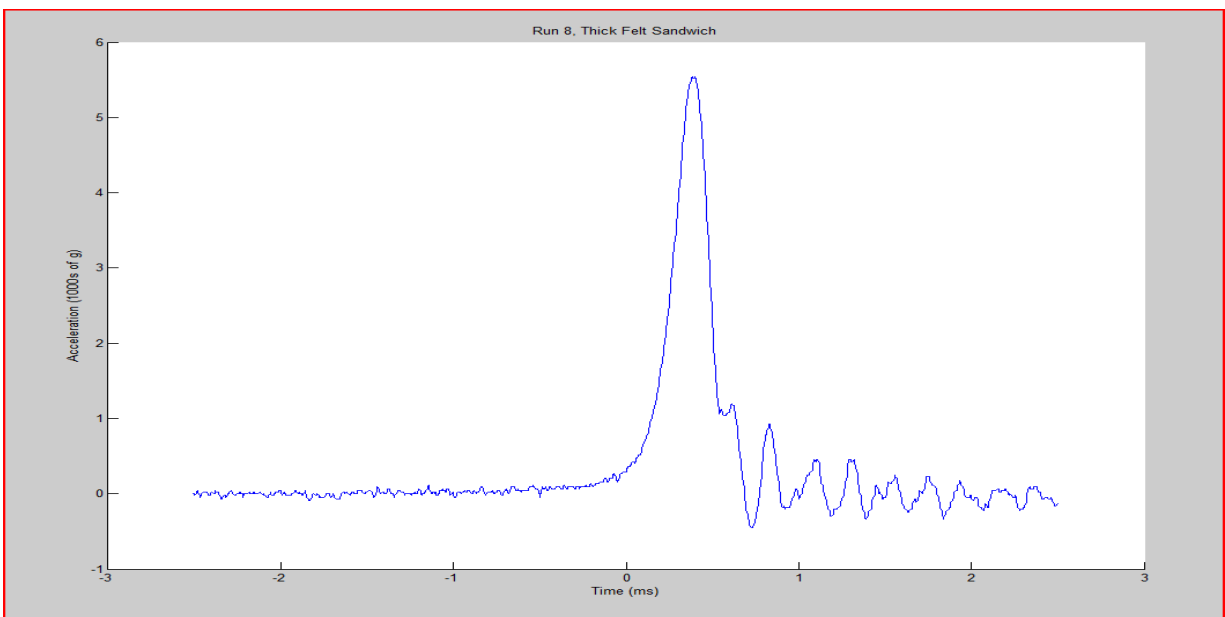

Figure 14. Trial 8: One thick piece of cardboard, 1 1/4-in fabric, and one thick piece of cardboard.
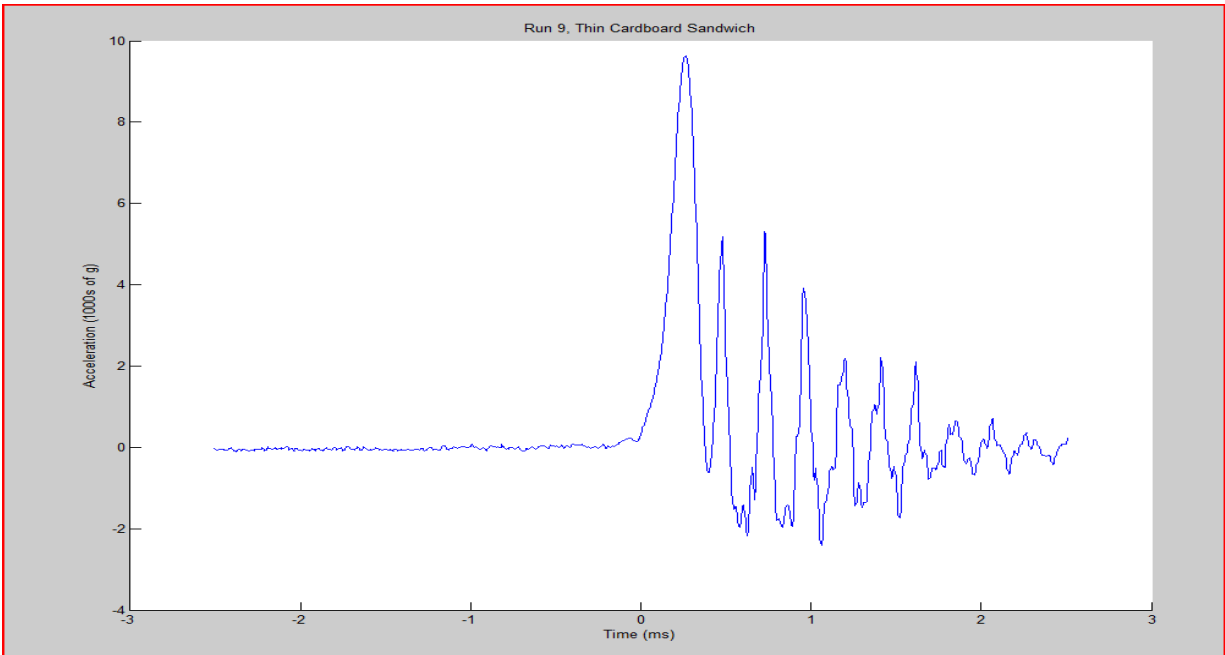
Figure 15. Trial 9: One 1/8-in fabric, four thin cardboard pieces, and one 1/8-in fabric.
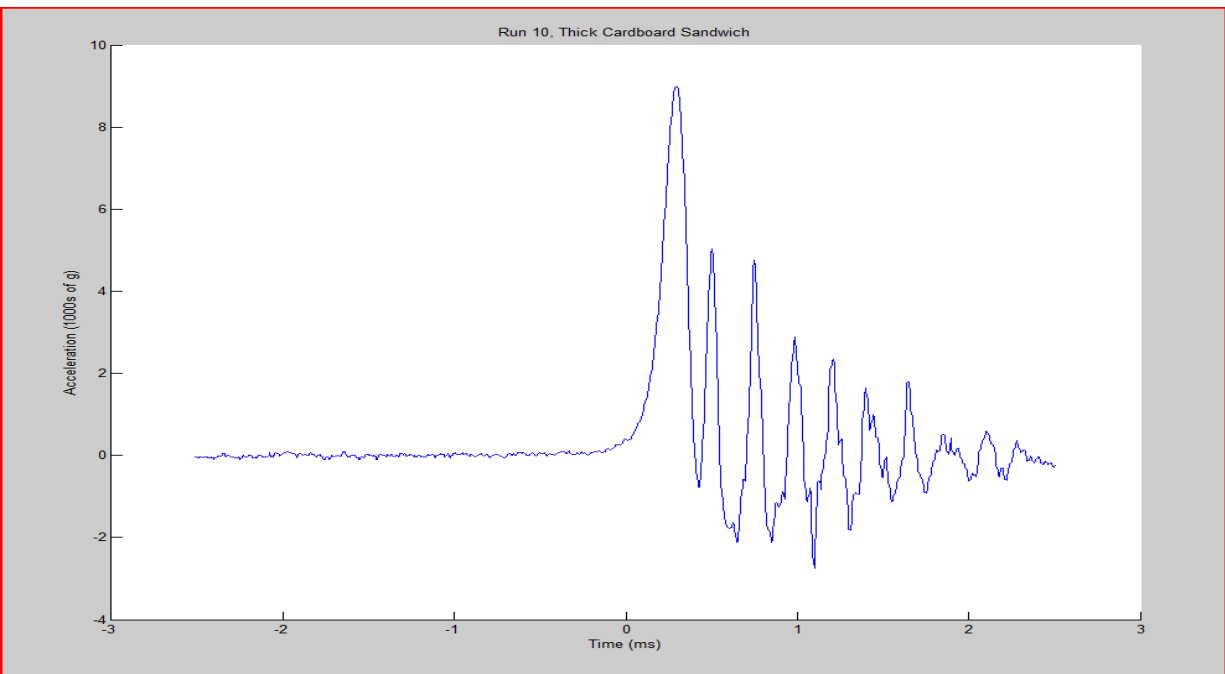

Figure 16. Trial 10: One 1/8-in fabric, one thick piece of cardboard, and one 1/8-in fabric.
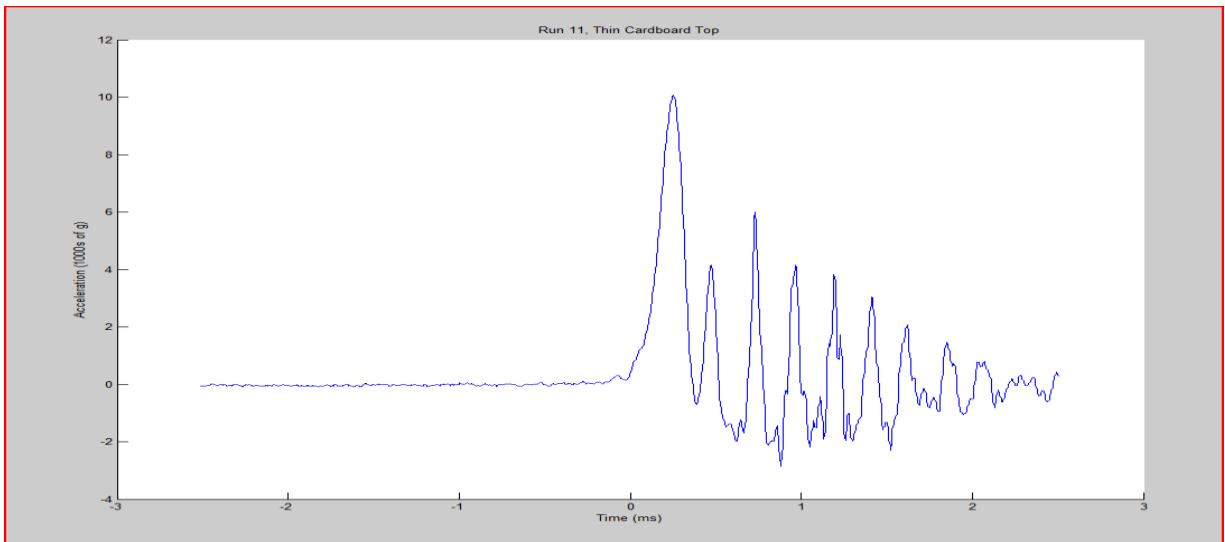
Figure 17. Trial 11: One 1 1/4-in fabric and four thin pieces of cardboard.
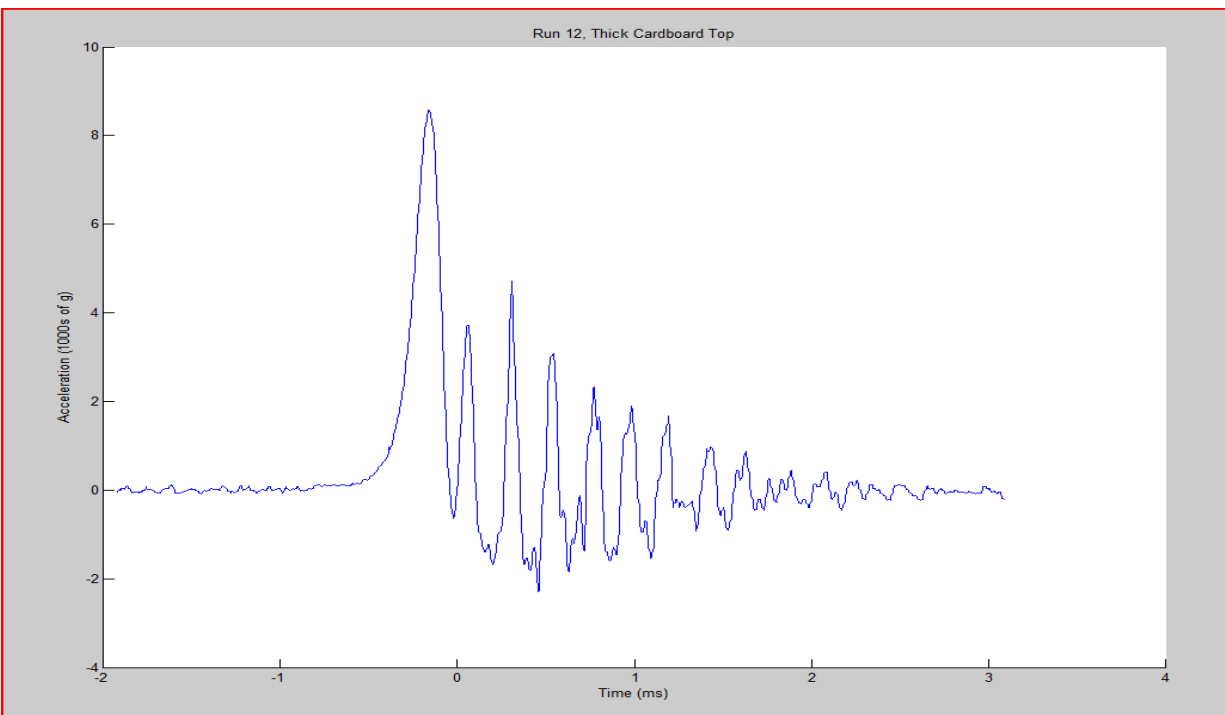

Figure 18. Trial 12: One 1 1/4-in fabric and one thick piece of cardboard.
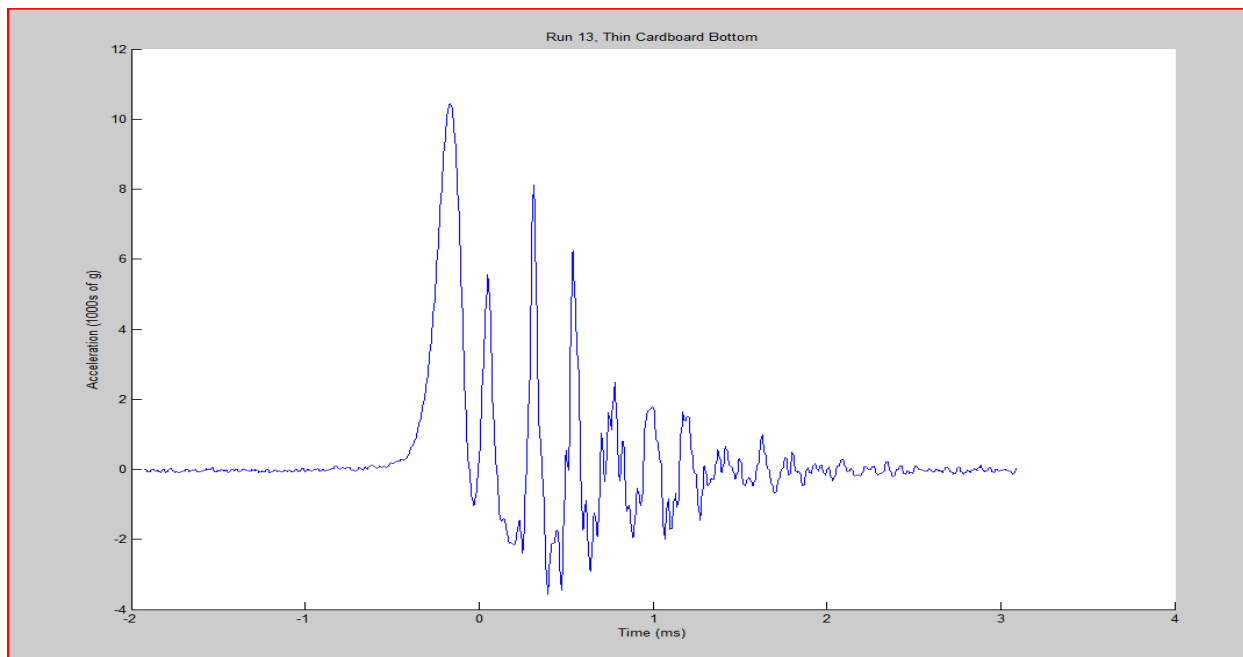
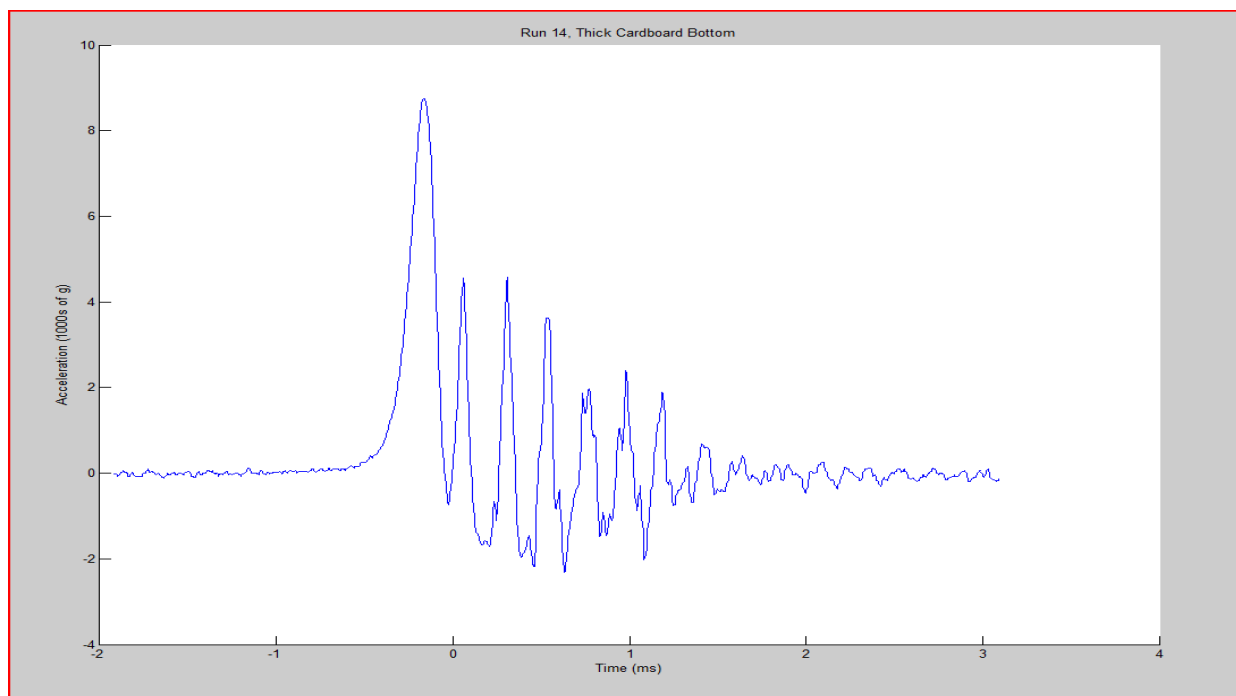Figure 19. Trial 13: Four thin cardboard pieces and 1 1/4-in fabric.

Figure 20. Trial 14: One thick cardboard piece and 1 1/4-in fabric.
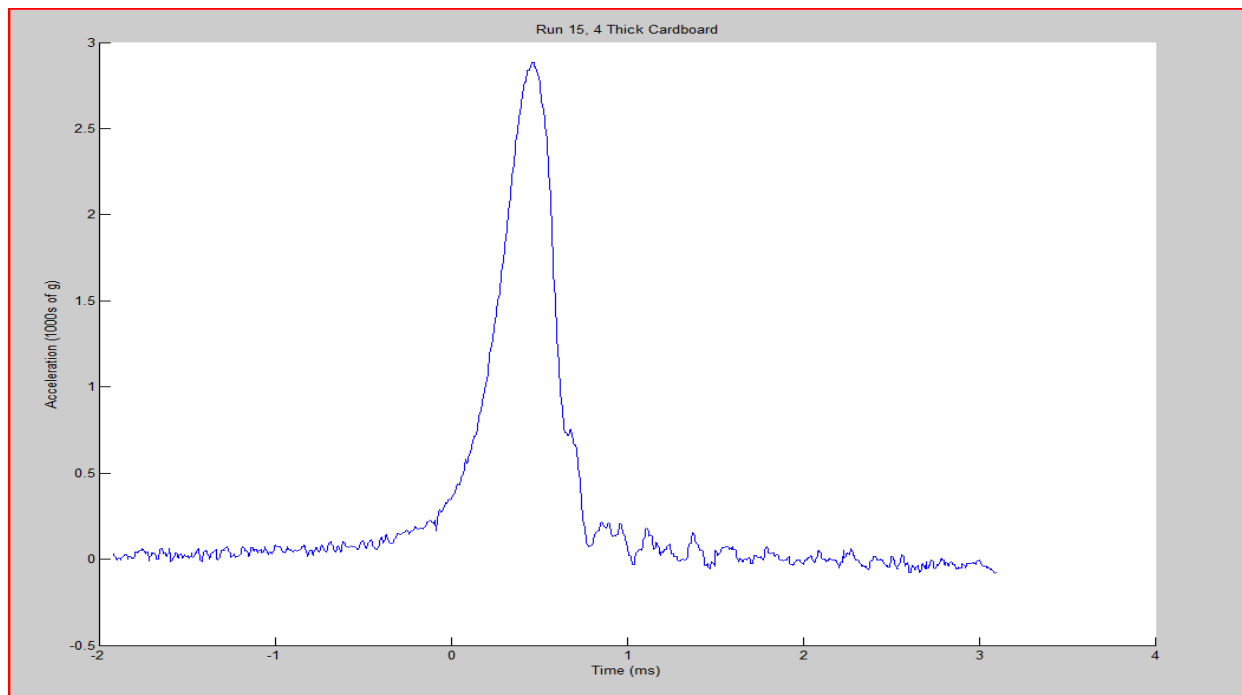
Figure 21. Trial 15: Four thick cardboard pieces.
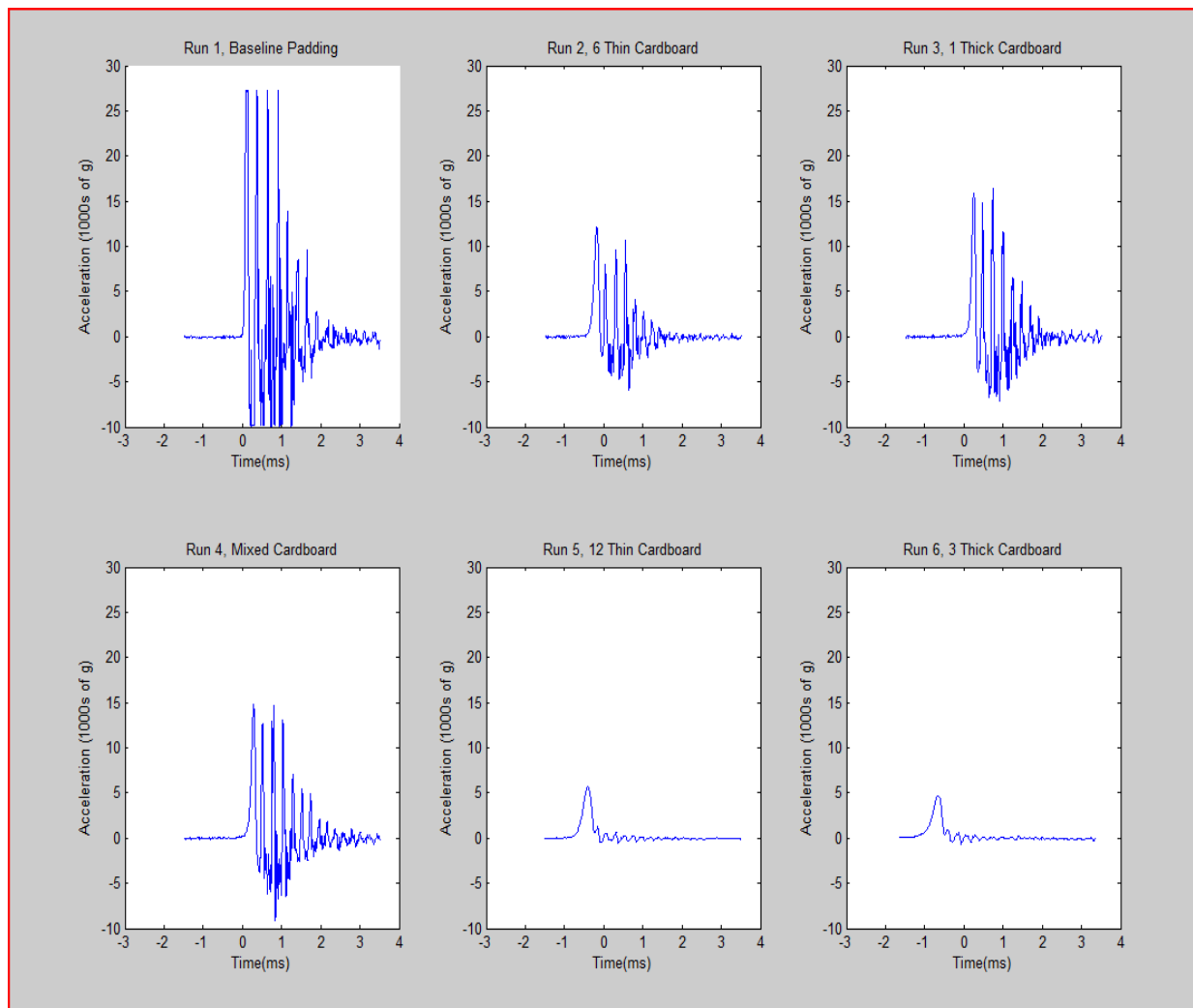
Figure 22. Trials 1–6 with the same scale.
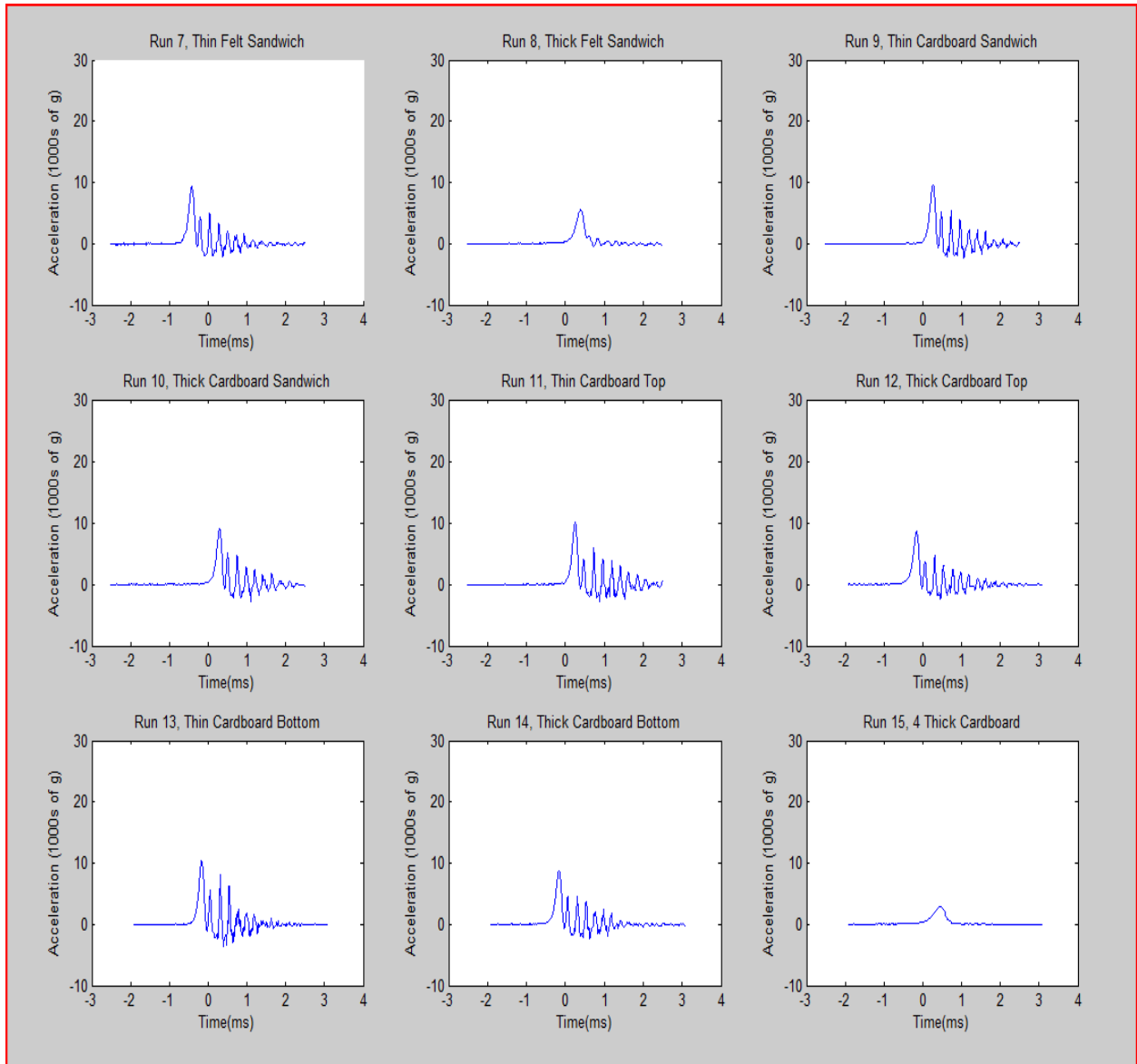
Figure 23. Trials 7–15 with the same scale.

Typical accelerations experienced by projectiles during launch will have a peak value in the range of 10,000–15,000 g's executed over a few milliseconds. The greatest challenge of the shock table test is prolonging the shock duration.

The trials with the least padding, trials 2 and 3, have a maximum acceleration from 12,200 to 16,400 g's, which is close to the acceleration that a projectile will experience upon launch. However, due to the erratic behavior of the acceleration during impact, this is not an accurate simulation of the change in acceleration during a typical launch.

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The shock tests that brought about a high acceleration also produced a phenomenon where there is a brief oscillation of a high shock value after the initial peak. This phenomenon, referred to as ringing, does not help in creating a shock test that resembles a projectile launch. As seen in the graphs, this phenomenon only appears in the trials that have less padding and makes it seem more desirable to use more padding when conducting a shock test to achieve gun launch acceleration patterns.

The trials with the heaviest padding, trials 5 and 6, have an impulse length of approximately 500 μm, which is more realistic than current shock tests. However, since the amount of acceleration applied to the anvil is less than 8000 g's, it would not be very useful. The oscilloscope was cut off during the baseline trial, so the true value of the maximum acceleration could not be determined.

Like the felt, the cardboard used in the shock experiment becomes permanently deformed. However, the cardboard becomes so deformed that it is unusable after being shocked once. After the cardboard is shocked it can be recycled. Also, it was noted that the bungee cord came off during shock test 5, which may have caused some error in the recorded data for that experiment.

5. Summary and Conclusions

These shock tests showed the difficulty of creating an accurate simulation of a gun launch. The acceleration graphs show that the reoccurring pattern in these shock tests was the more padding on the shock table, the longer the peak would last. However, the peak of the shock was limited to how much potential energy was put into the system. Therefore, it can be hypothesized that to create a higher, longer-lasting shock, more potential energy and more padding should be used.

The potential energy of the system could be increased by various methods. The maximum height of the machine could be increased to give the system more gravitational energy and more elastic potential energy from the bungee cord. Another option was to increase the mass of the anvil used in the shock machine, which would increase the gravitational potential energy of the system. A bungee cord with a higher spring constant could be put on the machine, which would increase the elastic potential energy of the system. Finally, the shock table could be modified in such a way that a second bungee cord could be attached to the system to increase the total elastic potential energy. To take the next step in this research, the shock table must be modified in some way to increase the energy put into the system.

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